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Report No.
TDR-169(3515-60)TN-1

A GENERAL STRUCTURAL CRITERIA USED IN SYSTEMS RESEARCH AND PLANNING DIVISION STUDIES OF NONRECOVERABLE BOOST VEHICLES

8 April 1963

J. R. Henry

Prepared For
COMMANDER SPACE SYSTEMS DIVISION
UNITED STATES AIR FORCE
INGLEWOOD, CALIFORNIA

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Prepared by J.R. Henry

Approved by A.G. Norem, Head
Structures and Materials
Department, SRPD

Approved by A. Mager, Director
Spacecraft Sciences
SRPD

FOREWORD

These generalized boost vehicle structural criteria are to be used for in-house SRPD structural design and analysis, inclusions in SRPD generated work statements and in requests for proposals, and a starting point for structural criteria for future systems. Although modifications to include the specific requirements of a particular vehicle are acceptable with proper justification and documentation, the intent of these criteria is to provide a consistent set of design conditions and requirements and thus supply the necessary foundation to insure that the systems under consideration have acceptable and compatible structural integrity.

ABSTRACT

This report contains a set of generalized structural criteria for the nonreusable boost vehicles of space launching systems and ballistic missile systems. Included herein are the basic objectives for the philosophy of structural design, a listing of the conditions and environments for which the vehicle must be investigated and designed, a summary of the requirements for establishing loads and other environmental factors for the design conditions and the requirements for establishing evidence of structural adequacy.

CONTENTS

CONTENTS (Continued)

I. SCOPE

A. Scope

This document presents the basic requirements and information governing the structural design of the non-recoverable boost vehicles of space launching systems and ballistic missile systems.

Included herein are:

1. Basic facts and references pertinent to the structural design.

2. Basic objectives for the philosophy of structural design.

3. Conditions and environments for which the vehicle must be investigated and designed.

4. Requirements for establishing loads and other environmental factors for the design conditions.

5. Requirements for establishing evidence of structural adequacy.

6. Definition of terms.

B. Authority

This document shall govern the design of all the boost vehicle structural components. Any deviation from these requirements shall be noted along with proper justification.

C. Intent

The intent of these criteria is to provide a set of design conditions, requirements, and objectives which, when implemented, will insure that the structural components achieve acceptable and compatible structural integrity. These criteria, after modification to include the specific requirements of a particular vehicle, will supply the strength and rigidity requirements of paragraph 3.3 of Reference (10).

II. DEFINITIONS, NOMENCLATURE AND REFERENCES

A. Definitions

1. Limit Load

Limit load is the maximum anticipated load, or combination of loads, which a structure may be expected to experience during the performance

of specified missions in specified environments. Since the actual loads that are experienced in service are random in nature, statistical methods for predicting limit loads shall be employed wherever appropriate.

2. Ultimate Load

Ultimate load is obtained by multiplying the limit load by the ultimate factor of safety.

3. Factor of Safety

The factor of safety is an arbitrary factor meant to account for uncertainties and variations from item to item in material properties, fabrication quality and details, and internal and external loads distributions.

4. Load Factor

Load factor is the ratio of the external forces other than weight acting on a mass to the weight of the mass.

5. Critical Condition

A critical condition is a loading condition for which the structure is to be designed.

6. Failure

A structure is considered to have failed when it can no longer perform its intended function. Failure of a structure may result in the loss of the vehicle, or any part thereof, and/or may present a hazard to operating personnel.

7. Excessive Deformations

Deformations, either elastic or inelastic, resulting from application of loads and temperatures are excessive when any portion of the vehicle structure can no longer perform its intended function without reducing the probability of successful completion of the mission.

8. Pressure Vessels

Pressure vessels are defined as containers that must sustain an internal pressure; for example, propellant tanks, solid motor cases, liquid or

gas storage bottles, plumbing, tubing, piping, etc., but not adapters, interstages, skirts, or fins even though these are acted on by internal or external pressure.

9. Nominal Pressure

Nominal pressure is the rated operating pressure of the system.

10. Maximum Expected Operating Pressure (MEOP)

This is the maximum anticipated operating pressure and includes the effects of temperature, transient peaks, variations in pressure and vehicle acceleration.

11. Limit Pressure

This is the MEOP defined above.

12. Ultimate Pressure

Ultimate pressure is the limit pressure multiplied by the appropriate safety factor.

13. Proof Pressure

Proof pressure is that pressure which is applied to a pressure vessel as a test at room temperature as evidence of satisfactory workmanship and material quality. Proof pressure is derived by multiplying limit pressure by the proof pressure factor.

14. Proof Pressure Factor

Unless specifically excepted, the proof pressure factor is defined as the ratio between the pressure vessel burst pressure at proof test temperature and that at the design temperature.

15. Burst Pressure

Burst pressure is the pressure which an article must sustain, as a singular load condition without rupture. For room temperature test purposes, burst pressure is the proof pressure multiplied by the appropriate safety factor. For design purposes at elevated temperature, burst pressure is equal to the ultimate pressure.

16. Erection Phase

The erection phase is defined as that time period from erection of the vehicle until removal of the gantry or other external support.

17. Prelaunch Phase

Prelaunch phase is defined as that time period from removal of gantry or other support until vehicle liftoff.

18. Post-Launch Phase

The post-launch phase is defined as that time period from vehicle liftoff until the launch transients damp-out.

19. Boost Phase

The boost phase covers the time period from launch transients damp-out to boost vehicle burnout.

B. Nomenclature

g = 32.2 feet per second
fps = feet per second
mph = miles per hour
psf = pounds per square foot

C. References

1.	MIL-HDBK-5	"Strength of Metal Aircraft Elements," March 1959
2.	NASA TN D595	"Reference Atmosphere for Patrick AFB, Florida, Annual," March 1961
3.	MIL-STD-210A	"Climatic Extremes for Military Equipment," 2 August 1957
4.	AFCRC-TN57-292	"Vertical Correlation of Wind Components" 29 March 1957
5.	WADD TR61-99	"Wind, Wind Shear and Gust Design Criteria for Vertically Rising Vehicles as Computed on the Basis of Montgomery, Alabama, Wind Data," April 1962

6.		"Handbook of Geophysics," the MacMillan Company, New York, 1960
7.	MIL-H-25475	"Hydraulic Systems: Design, Installation and Tests of Missile (General Specification for)," 1 September 1959
8.	MIL-P-5518B	"Pneumatic Systems: Design, Installation and Tests in Aircraft," 21 November 1957
9.	MIL-D-25869 (USAF)	"Data Requirements for Submission of Guided Missile Airframe Subsystem," 22 November 1957
10.	MIL-M-8555A	"Missiles, Guided: Design and Construction (General Specification for)," 6 October 1960

III. DESIGN CRITERIA

A. General Design Philosophy

The structure shall possess sufficient strength, rigidity, and other necessary characteristics required to survive the critical loading conditions that exist within the envelope of mission requirements. It shall survive those conditions in a manner that does not reduce the probability of the successful completion of the mission.

Consistent with the structural design principles and assumptions listed herein, the structure shall be designed to achieve minimum weight wherever practicable. Proper consideration shall be given to the effect on system cost and development schedule.

The structure shall be designed by the critical flight conditions wherever possible. The nonflight conditions and environments shall influence the structural design to the minimum extent. Wherever practicable, means shall be devised for assembling, handling, transporting and storing which do not require an increase in the flight weight over that required for the flight condition.

1. Design Conditions and Environments

The environmental phenomena corresponding to each design condition shall include all factors that can influence the structural design, and typically include heating, vibration, shock and acoustics, in addition to quasi-static and dynamic loads. Where possible all such phenomena shall be determined statistically.

a. External and Internal Load Distribution

External loads shall be determined by conservative analysis of the design environment. The aerodynamic loads may be determined from appropriate wind tunnel tests or calculated by conservative methods considered to be sound engineering practice. The effects of aeroelasticity on the distribution and intensity of loads shall be investigated by suitable methods.

Loads shall be distributed internally throughout the structure by suitable analyses. Effects of deformations, nonlinearities, and temperatures on internal load distribution shall be included in analyzing the load distributions.

b. Combined Loads and Internal Pressure

When internal pressure effects in combined load conditions are stabilizing or otherwise beneficial to structural load capability, the minimum limit internal operating pressure for that condition shall be used instead of the ultimate design internal pressure in the ultimate loads analysis.

c. Malfunctions

The vehicle structure shall not be designed to withstand loads produced by any subsystem malfunction that would otherwise result in failure to accomplish the mission. For manned missions, malfunctions shall not result in structural failures which substantially reduce the probability of successful crew abort.

d. Misalignment and Dimensional Tolerances

The effects of allowable structural misalignments, control misalignments, and other permissible and expected dimensional tolerances shall be considered in the analysis of all loads, loads distributions, and

structural adequacy. For establishing allowable loads, nominal skin gauges shall be used for analysis of multi-load path structures and minimum skin gauges for analysis of single-load path structures.

e. Dynamic Loads

Dynamic loads shall be determined for all quasi-static and transient phenomena expected in each design environment. The calculation of all dynamic loads shall include the effects of vehicle structural flexibilities and damping, and coupling of structural dynamics with the control system and the external environment.

f. Fatigue

The effects of repeated loads will be considered in the structural design. The design structural adequacy of the vehicle in flight shall not be impaired by fatigue damage resulting from exposure to nonflight and launch environments.

g. Vibrational and Acoustical Loadings

The effects of the vibrational and acoustical environments shall be accounted for in design wherever possible by suitable analysis of the response of the flexible system to the environment.

2. Material Properties and Allowables

a. Sources

Material strengths and other mechanical and physical properties shall be selected from authorized sources of reference, such as Reference (1), and from contractor test values when appropriate. Strength allowables and other mechanical properties used shall be appropriate to the loading conditions, design environments, and stress states for each structural member.

b. Values

Allowable material strengths used in design shall reflect the effects of load, temperature, and time associated with the design environment. Allowable yield and ultimate properties are as follows:

(1) For single load path structures, the minimum guaranteed values (A values in Reference (1)) are to be used.

(2) For multiple load path structures, the 90 per cent probability values (B values in Reference (1)) are to be used.

These values are to be consistent with over-all vehicle reliability requirements.

3. Strength Requirements

a. At Limit Load

The structure shall be designed to have sufficient strength to withstand simultaneously the limit loads and other accompanying environmental phenomena for each design condition without experiencing excessive elastic or plastic deformation.

b. At Ultimate Load

The structure shall be designed to withstand simultaneously the ultimate loads and other accompanying environmental phenomena without failure. No factor of safety is applied to any environmental phenomena except loads.

c. Margin of Safety

Margin of safety is defined as:

$$MS = \frac{1}{R} - 1$$

where R is the ratio of applied load (or stress, when applicable) to the allowable load (or stress). In determining the factor R the effects of combined loads or stresses (interaction) shall be included.

For minimum weight, the structural design shall strive for the smallest permissible margins of safety, which shall be zero, except in certain specific instances where specific finite values may be required.

4. Stiffness Requirements

a. Under Limit Loads

The structure shall not experience excessive deformations at limit loads and in the appropriate design environment.

b. Under Ultimate Load

Structural deformations shall not precipitate structural failure during any design conditions and environment at loads less than ultimate loads.

c. Aeroelastic Requirements

Destructive flutter or other related dynamic instability or divergence phenomena shall not occur on the vehicle, or its components, at any condition along the boost design trajectory. To assure safety, it shall be shown by analytical or experimental data, or both, that an increase of 15 per cent in equivalent airspeed at all points along the boost design trajectory both at constant Mach number, and separately, at constant altitude will not result in destructive flutter or divergence.

5. Thermal Requirements

The effects of temperature shall be considered in design of the vehicle. Thermal analysis shall be based on rational transient analysis of heat fluxes from aerodynamic heating, engine exhaust gas radiations, engine system and electronic equipment heat sources and including consideration of the heat sink effect of the mass of structure, fuel and equipment.

Aerodynamic heating shall be based on the design trajectories (see page 12). Aerodynamic heating rates shall be calculated using techniques considered to be in sound engineering practice.

Thermal effects on the structure, including heating rates, temperatures, thermal stresses and deformations, and mechanical and physical property changes, will be based on a critical design heating environment without an additional factor of safety, except for certain specific conditions where a specific factor of safety may be required.

6. **Factors of Safety**

a. **Flight Loads**

	Limit	Ultimate
Manned Payloads	1.00	1.40
Unmanned Payloads	1.00	1.25

b. **Nonflight Loads (Other than Pressure)**

	Limit	Ultimate
Dangerous to Personnel	1.00	1.50
Remote to Personnel	1.00	1.25

c. **Pressure Loads**

	Limit	Proof	Ultimate	Burst
Main Liquid Propellant Tanks				
Manned Payloads	1.00	*	1.40	1.40
Unmanned Payloads	1.00	*	1.25	1.25
Solid Rocket Motor Cases				
Manned Payloads	1.00	*	1.25	1.25
Unmanned Payloads	1.00	*	1.15	1..15
Liquid Propellant Thrust Chambers and Liquid and Solid Rocket Nozzles	1.00	*	1.25	1.25
Pneumatic Vessels Including Accumulators and Pressurization Bottles (See Reference (8))	1.00	1.67	--	2.22
Hydraulic Vessels Including Accumulators and Pressurization Bottles (See Reference (8))	1.00	2.00	--	4.00

*See Paragraph II-A Definitions

	Limit	Proof	Ultimate	Burst
Hydraulic Vessels Normally Under Oil Pressure Only (See Reference (8))	1.00	1.50	----	2.00
Hydraulic and Phenumatic Lines, Fittings and Hoses (See Reference (8))	1.00	2.00	----	4.00
Main Propellant Supply and Vent Components (See Reference (7))	1.00	1.50	1.88	----

B. Design Phases

1. Ground Phase

Structural design considerations shall include consideration of all environments to which the structure and its component parts are exposed during manufacturing, handling, transportation, erection and storage. Except for local attachments and structure such as aft skirts, the ground loads shall not govern design of the structure if practicable.

2. Prelaunch and Erection Phases

The vehicle shall be capable of sustaining all prelaunch and erection design load conditions while standing in the vertical position on the launch pad, in a silo, or in a transporter/launcher vehicle with full and pressurized, full and unpressurized, or with empty and unpressurized tanks.

The design load conditions may be induced by ground winds, gusts, engine thrust transients and differentials, stand misalignments, silo induced pressure and temperature, and such other conditions as may be experienced during the prelaunch or erection operations. Ground winds and gusts are specified in Section C.

a. Launch Release Loads (if applicable)

The launch release loads shall be determined by dynamic analyses. The effects of winds, gusts, control system operation, and thrust shall be included. Ground winds and gusts are given in Section C. Transient loads at launch, including dynamic effects shall be computed.

3. Post-Launch Phase

The vehicle shall be capable of sustaining all design load conditions as may be experienced during post-launch operations. Consideration shall be given to such effects as oscillation induced by launch release or ejection from a launch tube and subsequent motor ignition, etc.

4. Boost Phase

The vehicle structure shall be designed for the entire powered flight environment; the critical flight time and environment must be determined for each portion of the structure. It is likely that for most of the vehicle structure, the critical design conditions will occur in the vicinity of launch, maximum aerodynamic disturbance, maximum axial accelerations, maximum heating or stage separation.

a. Boost Design Trajectories

Design trajectories shall be developed in a statistical manner considering all pertinent trajectory parameters. An envelope of the design trajectories shall be established such that the vehicle will not operate outside of this envelope more than 1 per cent of the time. The trajectory calculations shall include, but not be limited to, consideration of the following: thrust level and variations, gyro drift, density variations, weight, and weight variations, etc.

b. Design Load Conditions

Dynamic and elastic effects shall be included in the determination of external loads. The effects of reduced modulus of elasticity due to increased temperatures, reduction in stiffness due to local buckling under load, and fuel slosh shall be included in the dynamic analysis.

Variations in significant vehicle parameters, which affect each particular loading condition, shall be evaluated and the resultant load variations combined statistically with the nominal load. The parameters shall be considered independently except where demonstrated correlation exists; in which case, the actual measured or estimated correlation coefficient shall be used. Considerations shall include, but not be limited to, variations and tolerances in: aerodynamic characteristics, positions of fixed surfaces, vehicle flexibilities, guidance and control system characteristics, thrust level, etc.

The design of the vehicle and its parts shall be based on, but not limited to, consideration of the following flight loads:

(1) Maneuvering Loads

Bending moments and axial loads resulting from flights along the critical design trajectories using the actual guidance and control system shall be determined.

(2) Wind Shear Loads

Loads induced by wind shears shall be computed considering flexible body dynamic and aeroelastic conditions. For specific vehicles with known launch sites and launch azimuths, the directional characteristics of the wind may be considered and the actual launch azimuth may be used. For all other systems, particularly weapons systems with unknown launch sites or azimuths and/or instant reaction time, the peak wind from the most critical direction shall be used for design. The design wind profiles shall be as specified in Section C. Compatibility with specific upper stages and/or payloads which are designed to limited wind shear loadings shall be considered.

(3) Gust Loads

Gust loads shall be considered along the boost phase trajectory for operations through 50, 000 feet altitude. The gust induced loads shall be determined by dynamic analyses. The resultant gust loads shall be added to the wind shear loads discussed above. The gust shall have the magnitude and shape specified in Section C. Compatibility with specific upper stages and/or payloads which are designed to limited wind gust loads shall be considered.

(4) Staging Loads

Staging loads shall be considered including, but not limited to, the consideration of engine shut-down transients, separation forces, engine start-up transients, vehicle motion due to wind disturbance, control lag, etc.

C. Geophysical Environment

This section specifies the geophysical environment to be used in the structural design of the vehicle. All items and components shall be designed for the most severe environmental conditions for the applicable geographical location with consideration of both operational and nonoperational states.

1. Atmospheric Properties

The appropriate standard atmosphere for the launch site shall be used, if available. Reference (2) represents the best available information for launches from the Atlantic Missile Range.

2. Ground Wind Profile

For systems that are to be launched from unknown or variable launch sites, the design ground wind profile shall be as specified in paragraph 2.7 of Reference (3). For convenience, the winds for portable devices at ordinary locations are plotted in Figure 1. The ground wind profile for Patrick AFB for a 1 per cent probability of exceedence for the worst season is given in Figure 2.

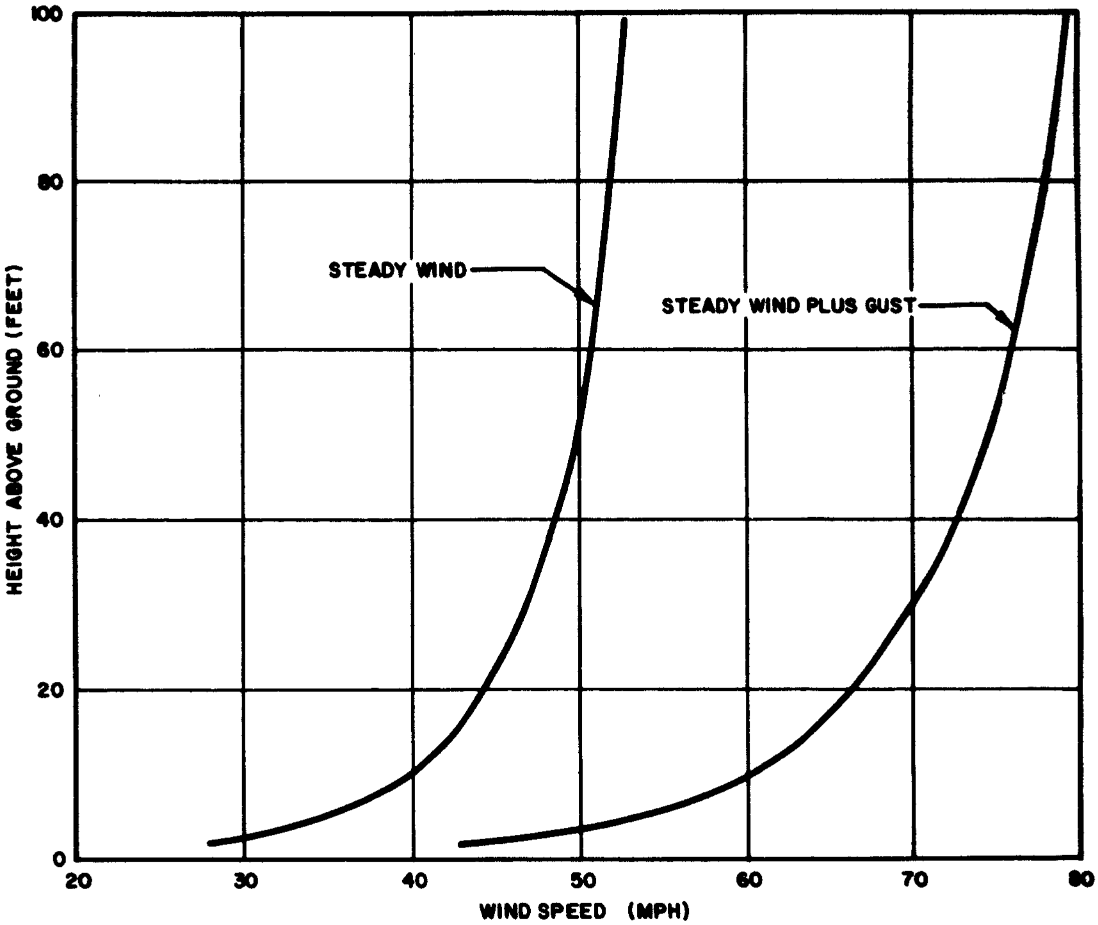

Figure 1. Ground Wind Profile.

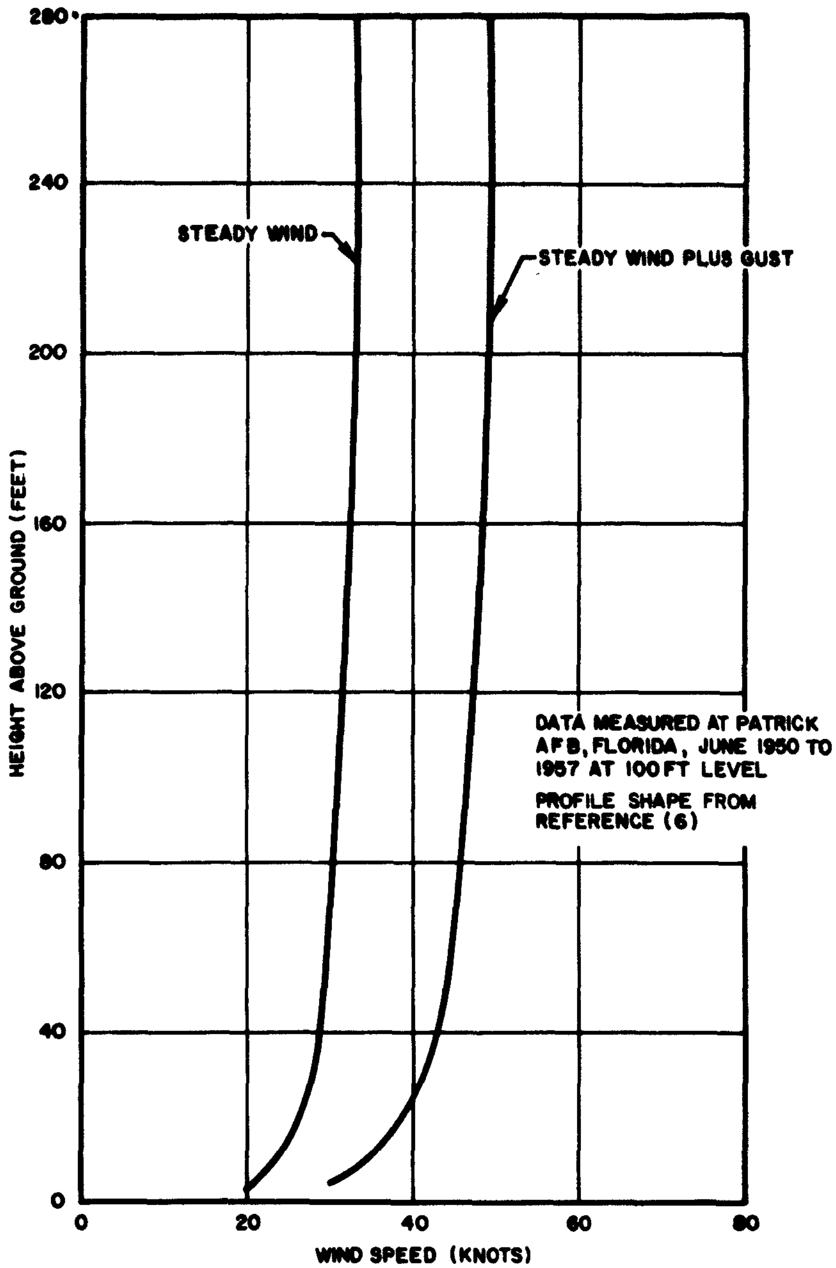

Figure 2. Ground Wind Profile - Patrick AFB.

3. Altitude Wind Profile

In developing the design loads for boost vehicles, the vehicle shall be analyzed for the fifty profiles given in Appendix E of Reference (5). These profiles shall be considered to yield loads that will not be exceeded more than 1 per cent of the time for launch sites within continental United States and Western Europe. For preliminary design purposes, the wind criteria listed below may be used.

The design altitude wind profile for ballistic missile systems launched within the continental United States and Western Europe is given in Figure 3 which is taken from Reference (4). For any assumed altitude, the following procedure shall be used to determine the peak wind velocity and the associated shears. The maximum wind velocity at altitude shall be obtained from the three sigma velocity envelopes shown in Figure 3. Wind shears shall be established for the first 1000 feet and next 2000 feet altitude increments above and below the altitude of interest. For the maximum wind at 41,500 feet, the 1000-foot shear rate shall be 0.07 fps per foot and the 2000-foot shear rate shall be 0.05 fps per foot. For any other altitude of peak wind, the above shear rates shall be multiplied by the ratio of the three sigma wind at the altitude to the three sigma wind at 41,500 feet. The wind profile above the point C need not be defined since the maximum load will occur below this level. Below point C the wind profile shall be determined by joining point C to the origin.

The design altitude wind profile for space launching systems is given in Figure 4, and is based on data contained in Reference (5). The wind profile presented there was increased by 15 per cent to reconcile the disparity between test and analytically predicted data. A single profile is formed by using the minimum envelope shown in Figure 4, transitioning to the maximum envelope by the desired shear and then returning to the minimum envelope with the same magnitude of shear. The dotted lines in this figure illustrate shears returning to the minimum envelope.

Loads shall be calculated on the vehicle for flying the minimum velocity curve, transitioning along the appropriate shear line to the maximum wind velocity enveloped and back to the minimum velocity curve. These loads shall be calculated for various transitions and the most critical one used for design.

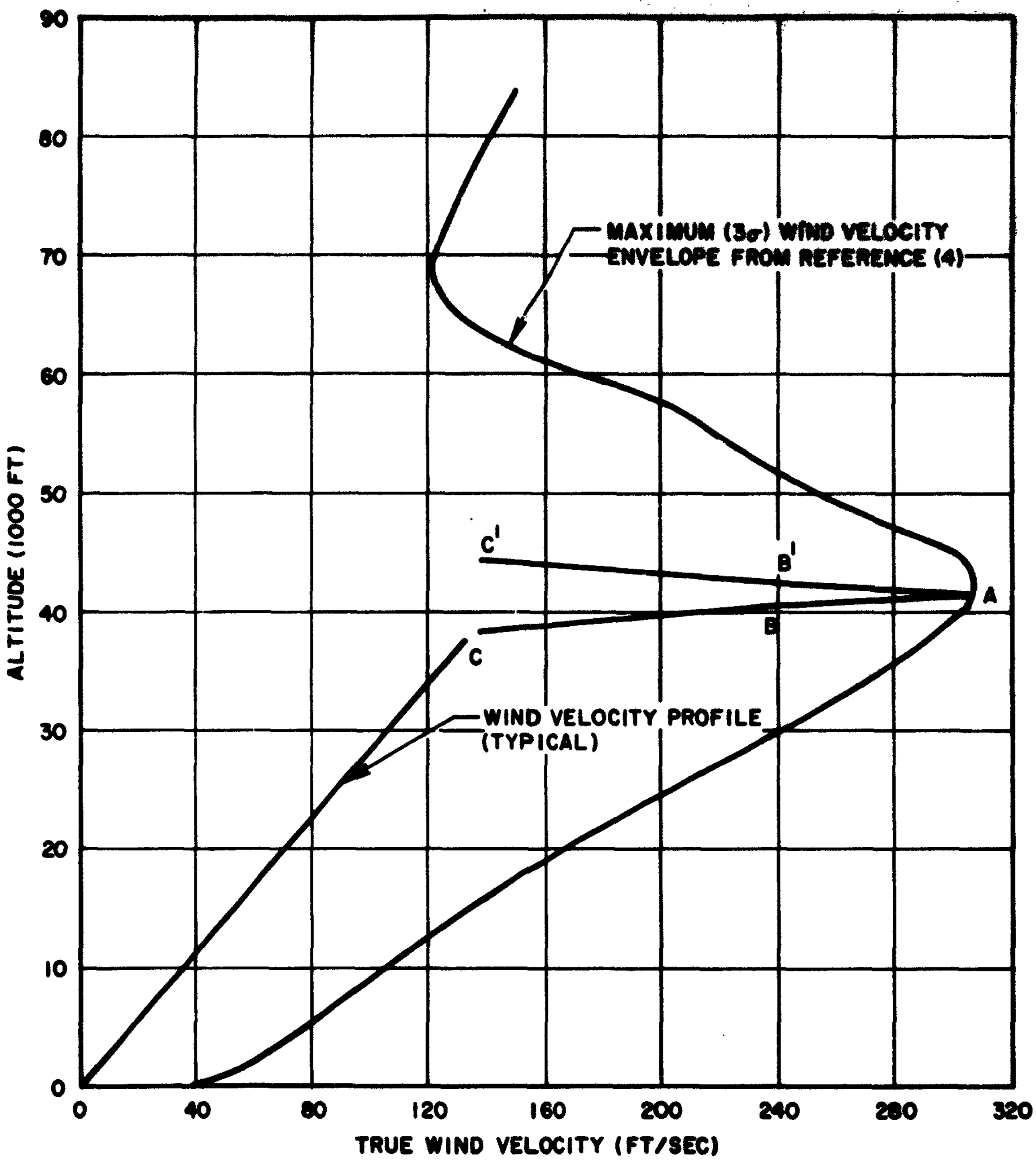

Figure 3. Altitude Wind Profile Ballistic Missile Systems.

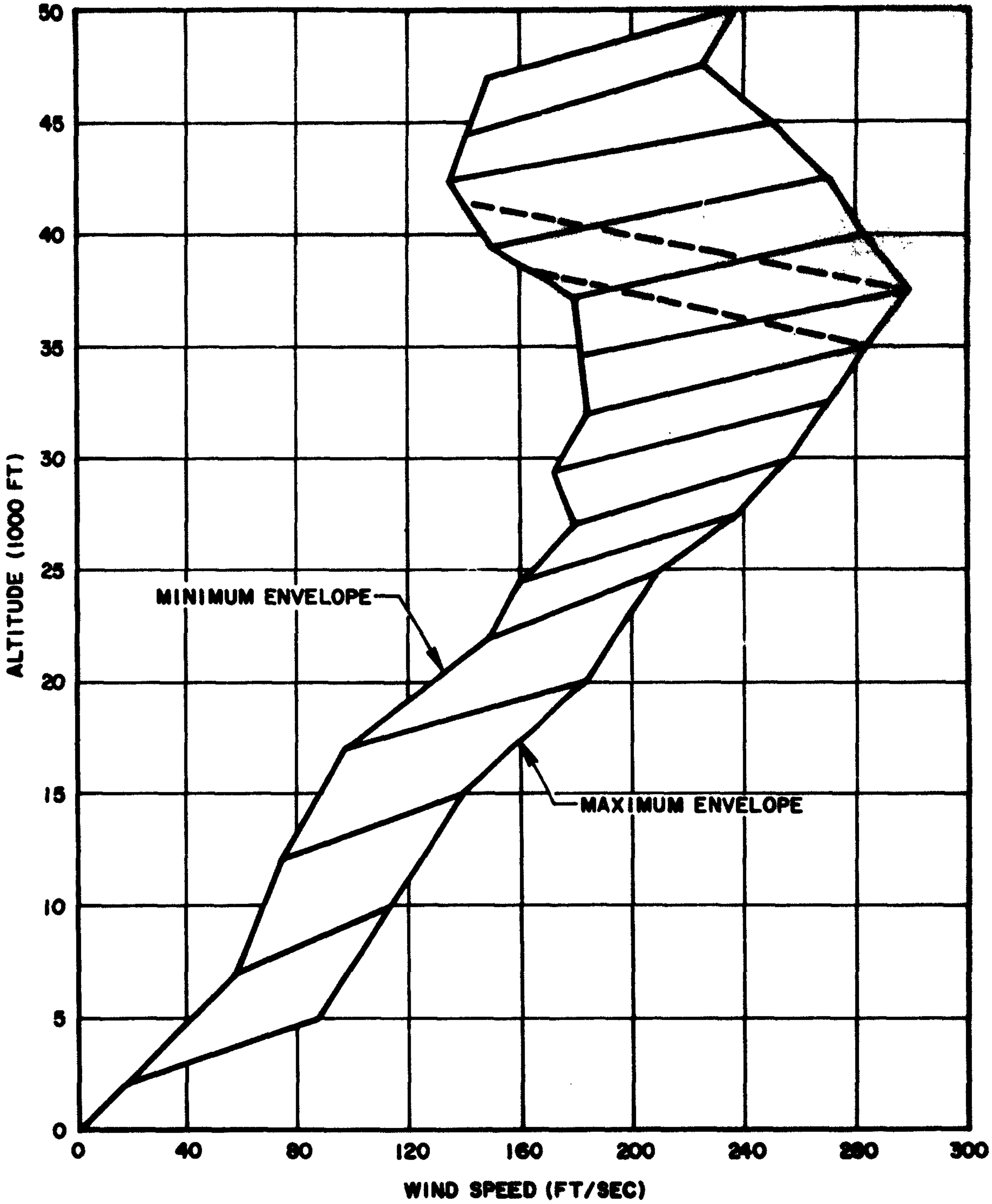

Figure 4. Altitude Wind Profile Space Launching Systems.

For systems with known launch azimuths and sites, the above wind profile may be applied in the true direction. The wind velocity versus compass points for Patrick AFB is given below normalized with respect to the west wind. Each profile shall be applied throughout a 45-degree segment composed of a 22.5-degree segment on each side of the compass point.

N	NE	E	SE	S	SW	W	NW
.53	.30	.11	.15	.53	.93	1.00	.78

4. Altitude Gusts

Altitude gusts shall have a (1 cosine) shape, and a gust velocity of 25 fps. The gust shall be tuned so that maximum flexible body response is obtained. The loads induced by the gust shall be added to the loads obtained from consideration of the wind profile.

5. Other Environmental Factors

Other environmental factors to be considered with respect to their effect on structure, materials, insulations, seals, subsystems, etc., shall include, but not be limited to, the following:

a. Humidity

b. Radiation

IV. REQUIRED ANALYSIS

A. Load Analysis

From the design loads and associated environments, the critical loads and/or critical combinations of loads and temperatures on the structure shall be used in an internal loads analysis to obtain the loads in the primary structure. The interactions of the various structural components shall be part of the internal loads analysis.

Thermally-induced structural loads shall be examined for both steady-state and transient temperature conditions. Test data shall be used along with theoretical analyses to obtain the temperature distribution throughout the vehicle structure.

B. Stress Analysis

The structural components shall be analyzed by the best available stress analysis methods. These methods shall be modified or replaced as necessary to account for the temperature state of the components being analyzed. Attention shall be given to the changes which occur in the physical and mechanical properties of the materials due to their temperature and load environments, and cycling through the service life spectra of the structure.

The thermally-induced strains and the load strains shall be combined in the analysis to determine the strength of the component parts. The manner in which this combination is made shall consider the strain cycle as applied in service.

C. Dynamic Analysis

Dynamic loads analysis shall be conducted in all cases where rapidly applied loads give rise to dynamic response of the vehicle or its component parts. The interaction of control system dynamics and structural dynamics shall be considered.

Intensities of shock, vibrations and noise vary with location in the vehicle and phase of the mission profile. The equipment and structure shall be designed to the environmental levels which are established for each particular location. In addition, the expected ground handling and transportation conditions shall be taken into account.

V. REQUIRED TESTS

A. Structural Confirmation Tests

The ability of the structure to sustain all critical design loads and environmental conditions in the manner required shall be demonstrated by structural confirmation tests. Such tests shall be performed on full scale representative specimens of individual components or assemblies of components.

When environmental conditions cannot be properly simulated in the test, allowances for material properties, combined loading and other missing effects shall be provided in the test procedure and loads. Where prior loading histories affect the structural adequacy of a test article, these shall be included in all test requirements. Adequate instrumentation shall be provided in order to properly evaluate the results of these tests.

Structural tests that have previously been conducted for other programs may be substituted for tests required by this criterion, providing the structural component was essentially identical and the applied loading was either the same or more severe than required by this criteria. Adequate documentation must be submitted prior to substituting previous tests for tests required herein.

B. Dynamic Tests

1. Ground Vibration Survey

Ground vibration tests shall be conducted on the vehicle for the purpose of experimentally determining natural frequencies, mode shapes and structural damping. The measured data will be compared with calculated results and subsequently used in dynamics and control system stability analyses as required. The structure shall be complete in every detail and all major installed masses shall be simulated in order to represent correct center of gravity locations and moments of inertia. The mounting or support system shall be compatible with the conditions being simulated. Liquid fuel dynamic effects shall be measured through the use of simulated or actual fuels.

2. Rigidity Verifications

The rigidity of the vehicle (or separate parts) shall be verified. The minimum verification required shall be that achieved through correlation between calculated and measured mode shapes and frequencies. If analyses or tests indicate low margins on flutter, or other dynamic instabilities, structural rigidity or influence coefficients tests shall be used for rigidity verification.

3. Fatigue and Acoustical Tests

Fatigue tests shall be performed, as necessary, on representative structural specimens to demonstrate adequate fatigue life under vibratory loads. Excitation sources such as horns, sirens, engines and mechanical exciters, as well as true sources (with the vehicle under simulated operating conditions) shall be utilized as appropriate in simulating the vibratory loads.

C. Pressure Vessel Tests

All pressure vessels shall be subjected to the following structural static and fatigue tests. These tests are designed to prove the structural integrity of the design for a particular application (Design Confirmation Test) and to indicate the quality of subsequent production vessels (Acceptance Tests).

1. Design Confirmation Tests

The design confirmation test shall consist of the applicable tests listed below. Tests a. through d. shall be conducted on the same vessel in the order listed.

a. Preliminary Leakage Test

The vessel with all openings sealed and with a minimum of external support shall be subjected to air pressure equal to one-third of the normal operating pressure for a minimum period of fifteen minutes to check for leakage. Leakage, as indicated by a pressure drop during this time period, shall constitute failure.

b. Flow Test

If there are analytical indications of the possibility of failure of the vessel or internal structure due to ram effects, or due to negative pressure as a result of the entrance flow of the fluid, a flow test shall be conducted. The rate of flow, valve type and size, and entrance line diameter shall duplicate that used in service. Inspection of the vessel after the test shall show no indications of failure.

c. <u>Slosh and Vibration Test</u>

If there are analytical indications of the possibility of failure of the vessel due to slosh and/or vibration then the vessel shall be filled two-thirds full with the intended fluid and sloshed in a manner duplicating service conditions as to angular velocity, acceleration and displacement. If the vessel is to be subjected to prolonged and/or intensive vibration, it shall be subjected to a vibration test in conjunction with the slosh test. The effects of non-ambient temperatures likely to be experienced in service shall be suitably accounted for during the conduction of this test.

The amount of contained fluid may be varied if another fluid level can be shown to be more critical on the basis of analysis or the testing of similar vessel designs.

d. <u>Hydrostatic Tests</u>

The vessel shall be pressurized hydrostatically to determine the permanent set or yielding at limit pressure and the failure or burst strength at ultimate pressure. The vessel shall have its adjoining structure installed as in the actual vehicle, or this adjoining structure can be simulated. The vessel carry-through loads shall be applied to the adjoining structure. Pressure shall be applied in increments, noting the volumetric displacement. However, after exceeding an increment of pressure above 40 per cent of the limit test pressure, and upon each increment thereafter, the pressure shall be reduced to 40 per cent of the limit test pressure and the lack of volumetric recovery, or "permanent set," shall be noted. This method of observing the behavior of the vessel shall be continued through all loading conditions to failure.

e. <u>Fatigue Test</u>

Fatigue tests shall be conducted on scale vessels of each design where appropriate. If the fluid used in such tests is not the propellant employed in service, and if the propellant has a deleterious effect on vessel strength, such effects shall be simulated in this test. The external loads

experienced in service shall be simulated and applied to the vessel in conjunction with the pressure loads. Previous to the fatigue test the vessel shall be hydrostatically tested to the proof pressure in accordance with the procedure outlined above.

f. Static Firing Test

The structural adequacy of solid motors shall be demonstrated by firing of a flight weight motor using production motor cases, internal insulation, propellant and nozzles. If there are indications of the possibility of failure of the pressure vessel or internal structure of liquid propellant vehicles due to static firing, then the structural adequacy of the vessel shall be demonstrated by conducting a static firing test. The vessel shall be mounted in the same manner that is used in the flight vehicle and all carry-through and pressure loads shall be applied. The engine shall be fired for its design duration and, where applicable, the loads induced in the vessel by engine gimballing, etc. shall be applied. Inspection of the vessel after the test shall show no indications of failure or indicate a malfunction of related equipment or components.

2. Acceptance Tests

Every pressure carrying component delivered shall be tested in the following manner:

a. Preliminary Leakage Test

All vessels shall be checked for leaks in the manner as specified in Section V-C.

b. Proof Pressure Test

All vessels shall be proof pressure tested in the same manner as specified in Section V-C for hydrostatic yield testing. During this test the vessel shall not leak. For vessels for which a proof pressure test cannot be performed or is meaningless, i. e., filament wound glass vessels, a sampling of burst tests of production articles may be substituted.

c. <u>Post Leakage Test</u>

After completing the proof pressure test, the vessels must be checked for leaks. If the vessel develops leaks during the proof pressure test, such leaks shall be considered cause for rejection of the vessel unless they are not the result of a structural failure. Otherwise, the tank may be repaired in a manner which does not reduce the ultimate or the fatigue strength of the vessel. The vessel shall be proof pressure tested after repair.

VI. REQUIRED PROGRAM DOCUMENTATION

The specific program documentation described in paragraphs 3.3.2, 3.3.5, 3.3.6, 3.3.7, 3.3.9, and 3.3.10 of Reference (9) are required. Procedures and dates of submittal shall be as defined in Reference (9) unless otherwise specified.

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Unclassified Report

This report contains a set of generalized structural criteria for the nonreusable boost vehicles of space launching systems and ballistic missile systems. Included herein are the basic objectives for the philosophy of structural design, a listing of the conditions and environments for which the vehicle must be investigated and designed, a summary of the requirements for establishing loads and other environmental factors for the design conditions and the requirements for establishing evidence of structural adequacy.

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